WJEC (Wales) Physics GCSE

2.6: The Universe

Detailed Notes

(Content in **bold** is for higher tier **only**)

Emission & Absorption Spectra

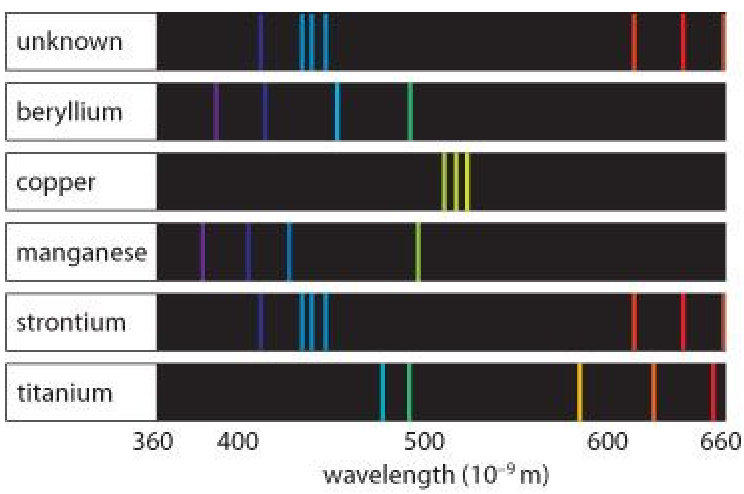
Line spectra are produced to help **identify elements** present in stars.

When substances are **very hot**, they **emit light**. Light can be viewed through a **diffraction grating** as a **continuous spectrum** where wavelength and frequency gradually change. Hot gases don't emit a whole spectrum, only **specific** frequencies or wavelengths. Using knowledge of which **frequencies** correspond to which **elements**, we can identify the **composition** of the gas in a star.

Emission Spectra

A **line emission spectrum**, produced from light emitted by an element in a hot gas, is specific to that element. Therefore a hot gas cloud, as a whole, will release an emission spectrum comprising a **series of light frequencies** collating the emission spectra of all the individual elements contained within the cloud.

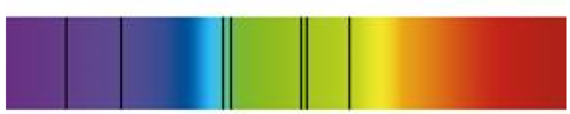
Since the line emission spectra of individual elements are known, the line emission spectra of hot gases can be used to **identify** the elements present in the cloud. In this respect, line emission spectra act like a **chemical fingerprint**.



Emission spectra for several elements. By matching the patterns, it can be seen that the unknown sample matches that of Strontium (wps.pearsoned.com.au).

Absorption Spectra

When a gas **cools**, it **absorbs** the same frequencies of light that it would emit if hot. Therefore if a continuous spectrum of light is passed through a cool gas, absorbed frequencies appear as **dark lines** as they are **'taken in'** by the gas cloud between the observer and the light source.



Absorption spectrum showing the absorbed frequencies as thin black lines (adapted from circlingsquares.blog).

Using this knowledge, we can figure out what elements are present in a particular cool gas, by passing a continuous spectrum of light through it and observing the absorption spectrum produced.

In the early 19th century a German physicist called Joseph von Fraunhofer invented the **spectroscope** allowing absorption spectra to be observed for the first time. Through the 19th century, scientists were able to use their understanding of absorption spectra in order to identify elements present in the Earth's atmosphere.

The Doppler Effect & Red Shift

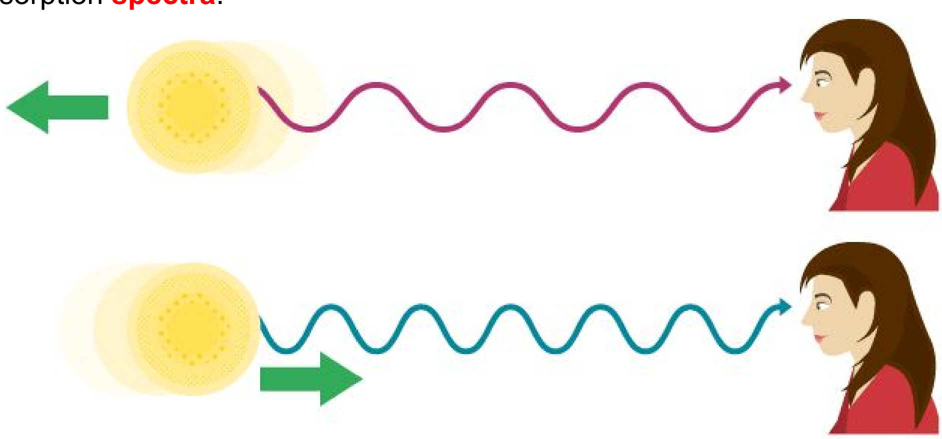
If a sound source is **moving** relative to an observer, the wavelength of the emission (pitch) heard by the listener will be **compressed** or **extended** depending on whether the source is moving towards or away from the listener. If the source moves **towards** the listener, the waves will be **squashed** together so wavelength is **reduced**. Therefore the pitch heard will be higher. If the source **moves away** from the observer, the waves will be **stretched** so wavelength is **increased**. Therefore the pitch heard will be lower. This concept applies to all waves and is called **Doppler shift**.

Example
A common example is the sound of an ambulance siren. As it approaches, the sound appears higher in pitch (shorter wavelength) than when it moves away, where it has a lower pitch (longer wavelength).

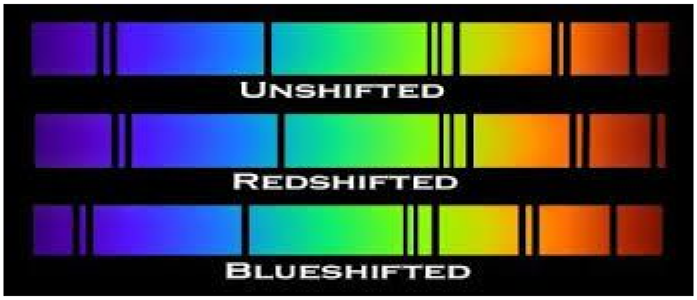
Red Shift

Since light is an EM **wave**, the doppler effect applies. As for sound, the doppler effect changes the wavelength of the waves emitted. The wavelength of light affects its colour. So the **colour of light** emitted by moving objects varies.

As the planet **moves away** from the observer, the light wavelength is **stretched** so the light changes to be closer to the **red** end of the spectrum. This is **red shift**. As the planet moves **towards** the observer, the light wavelength is **compressed** so the light changes to be closer to the **blue** end of the spectrum. This is **blue shift**. These shifts can be observed on the line emission or absorption **spectra**.



Graphic depicting how relative movement of the emitter/reflector of light, with respect to the observer affects its wavelength (bbc.co.uk).



Shifted absorption spectra (coolcosmos.ipac.caltech.edu).

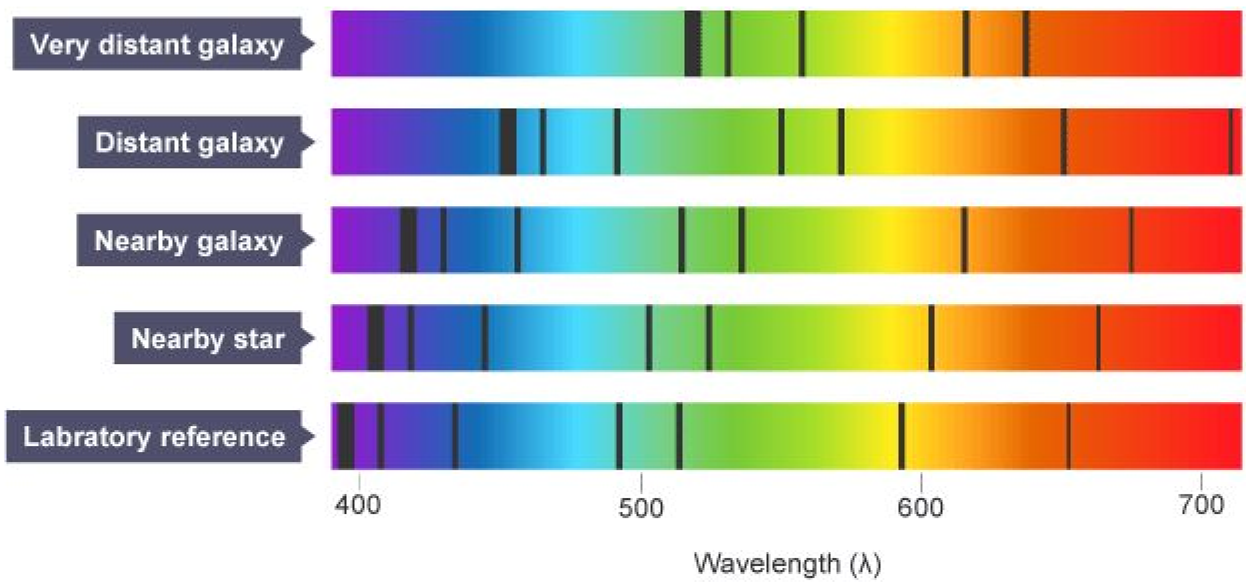
Cosmological Red Shift

This phenomenon was first hypothesised and observed by **Edward Hubble** in the 20th century. Hubble observed the **absorption spectra** of many different galaxies and saw that they displayed the **same relative pattern** as that for our sun. However, the absorbed lines appeared to be **red shifted**.

This means these galaxies must be **moving away** from the Milky Way (our galaxy) and so Hubble concluded that this cosmological red shift was caused by an **increasing distance** between galaxies. This provides evidence for an **expanding universe**.

Hubble's Law

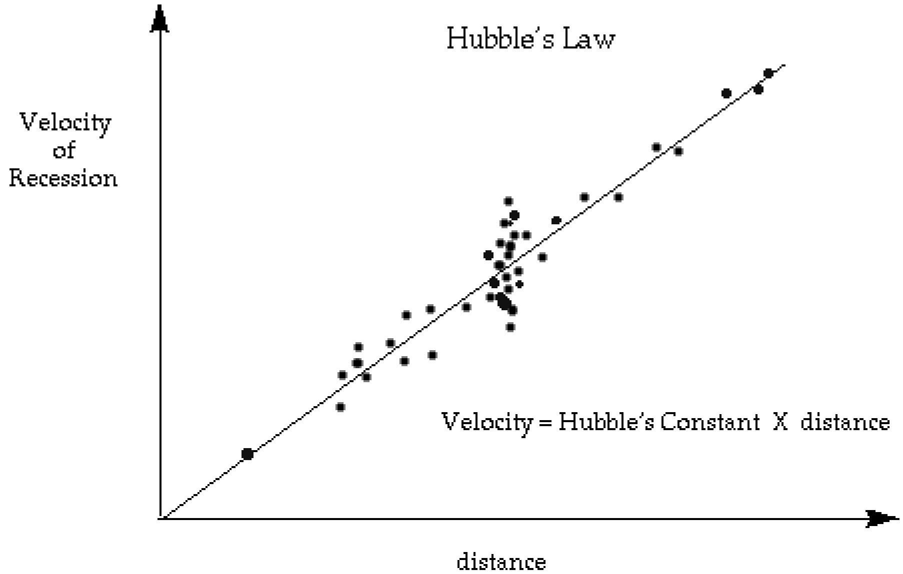
Hubble also observed that the **further away** the galaxy was, the **more red shifted** the emitted light was. He suggested that this is because the emitted light has travelled a much **greater distance** and for a **longer time** as the universe continues to **expand**. Therefore a correlation between the distance of these galaxies from the Earth and the degree of red shift can be drawn.



Relative red shifts of galaxies and stars compared to Earth (bbc.co.uk).

Hubble calculated the **velocity** with which the distant galaxies must be **moving away** from Earth (**velocity of recession**) and plotted them against **distance** from Earth to demonstrate this correlation. It plots as a **straight line** through the **origin** with the gradient of the line being called **Hubble's constant (H_0)**.

The **reciprocal** of Hubble's constant ($1/H_0$) can be used to estimate the **age of the universe**. Using this, Hubble estimated the universe to be **~14 billion years old**. Today we estimate it to be **13.7 billion years old**.

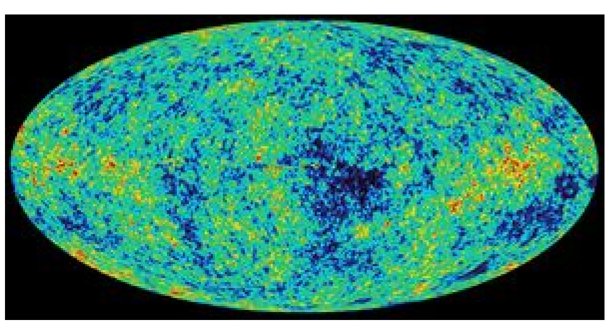


Graph showing Hubble's law (misswise.weebly.com).

Cosmic Microwave Background Radiation (CMBR)

In the 20th century, it was proposed that the universe came from a **single point** that **exploded** out in the Big Bang. The analysis of **red shifted signals** from far away galaxies by Hubble provided good evidence for this and also suggested the universe is **still expanding**.

If the universe began with an explosion, it would be expected that **radiation** from this explosion would **still exist** and be **detectable**. This radiation was detected for the first time in 1964 as **microwave radiation**, part of the CMBR.



The CMBR detected from Earth (keystagewiki.com).

The CMBR also provides good evidence for a **continually expanding universe**. Initially in the explosion, **high energy, short wavelength gamma radiation** would have been released. However, **lower energy, longer wavelength microwave radiation** is now detected. It has been suggested that as the universe expands, the gamma waves have had to **travel further** and so have **red-shifted** (stretched/increased in wavelength) into the microwaves detectable today.